Use of Time Series SAR Data To Resolve Ice Type Ambiguities In Newly-opened Leads

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Abstract

The backscatter signature of sea ice in newly-opened leads frequently overlaps with that of older and thicker ice types. This phenomenon limits the accuracy of backscatter based ice type classification in single date SAR images. Here, we use ice motion data derived from successive SAR observations to identify areas of recent openings in the winter sea ice cover. With the assumption that the backscatter of a new lead adds to a nominally invariant backscatter histogram. we can calculate the area of new ice which has been created and record the temporal evolut ion of backscatter of the new ice. This temporal signature is related to atmospheric conditions during the rapid growth phase of the new ice. We illustrate the use of time series information with ERS-1 SAR data from the Alaska SAR Facility.

1. Introduction

The backscatter signature of ice in recently formed leads is dependent on environmental conditions and evolves quickly under cold Arctic conditions. Typically, the backscatter changes associated with these young ice types are on length scale of days [*Onstott*, 1992]. This signature variability is a source of error in the correct classification of this ice type in single date, single frequency and single polarization SAR data. The backscatter of this thin ice type frequently overlaps with that of the principal or dominant (in terms of area) multiyear and first-year ice types. Although the fractional area of thin ice (0-50cm) is small in the winter Arctic, the total heat flux (from the relatively warm ocean to the cold atmosphere) from this thin ice fraction can be comparable to that of the principal ice types. Unambiguous identification of the areal fraction of young thin ice types is important for a variety of scientific and operational applications.

Here, we illustrate with an example our approach to identify recently for med leads as well as obtain a record of the temporal evolution 'of backscatter signature of sea ice in these leads.

2. Data Description

SAR data. We use a time sequence of five calibrated ERS-1 SAR images which were processed at tile Alaska SAR Facility (ASF). The sequence spans a period of 12 days (from day 77 to day 89) wit h an interval of three days between consecutive images. The centers of the five images were located at approximately 73.3° N and 153. 7°W.

Ice Motion data. In order to record the temporal evolution of the backscatter signature, we need the capability to follow or track an open lead for a period of time. In the example shown here, an ice motion tracker similar to the one implemented in the ASF Geophysical Processor System [*Kwok et al.*, 1990] was utilized to follow an ice parcel over the period of 12 days. We define an ice parcel as an element of area enclosed by straight line segments connecting four points (see Fig. 1) which moves and deforms with the sea ice cover. Figure 1 does not show the mean ice motion of the grid points, only the deformation of the ice parcel,

3. Data Analysis - An Example

Openings in the ice cover. Openings in the ice cover can be seen as positive changes in the area of the ice parcel. The increase in area, between Day 077 and Day 0S6, due to the opening of a lead, is evident. The area changes of the ice parcel as a function of time are plotted in Figure 1b. This ice parcel had an initial area of 2500 units. Over the first time interval (Day 077 to Day 0S0), the area increased to 3034, giving a young ice class (opening) an area of 534 units. The cell area increased to 3205 and 3317 during the second (Day 060 and 0S3) and third (Day 083 and 086) time intervals, creating 171 units and 112 units, respectively. A closing event (between Day 086 and 089) caused a decrease in area from 3317 to 3235, or 82 units. Errors in estimating the actual areas are deter mined by advection of ice across the boundaries defining the ice parcel (i.e. the boundaries are not straight line segments) and errors in the ice t racker.

The backscatter histograms. here. we address the interpretat ion of the radiometric changes within the ice parcel due to the area changes. We compute three sets of histograms. The first set of histograms reflects the backscatter of the pixel population within the ice parcel during each of the five days (Fig. 2). The second set (Fig. 3) shows the relative changes in backscatter population between time intervals, Fig. 4 shows the last set which displays the changes in the back scatter population relative to the first. day. If we assume that the source of all backscatter changes is clue to the young ice, then we can track the evolution of the backscatter of the new leads using the difference histograms. How good is this assumption? (-rider Arctic winter conditions, it has been shown [*Kwok and Cunningham*, 1994] that the backscatter signature (at C-VV) of the principal ice types (multiyear and first-year) remain remarkably stable over the winter. This conclusion was based on their study using ERS-1 SAR image data from two different winters, So, it is reasonable to assume that for a short time span, if environmental conditions stay relatively stable, the only contribution to changes in backscatter within an ice parcel is from young ice. In this case, we eliminated the possibility that the high backscatter is wind-roughened open water because of structure in the leads as well as the air temperature of the atmosphere. At a temperature of approximately -30°C, it takes only hours for ice to grow, In the example in Fig. 1, we can observe that there is a gradual decrease in the brightness of the lead as the ice in it grows and thickens. The backscatter histograms quantify the temporal evolution of the backscatter. For example, the histograms in Fig. 3 show that there is an increase in pixel population between day 80 and 77, and there is a large decrease in the brightness of the lead between day 86 and 83. The histograms in Fig. 4 show that evolution of the radar backscatter of the population of young ice which was introduced into the ice parcel on day 77. "The backscatter change as a function of time is plotted in Fig. 5. The air temperature is shown on the same plot.

4. Discussion

The particular example which we have chosen shows a lead with initially high backscatter which decays with time. In our experience, we have observed in ERS- 1 SAR (C-VV) imagery a large number of open leads containing sea ice with high initial backscatter with similar backscatter history We have also observed cases where the backscatter of sea ice in leads remained relatively low for an extended period of time (days) and slowly attaining the higher backscatter of thicker first-year ice. We cannot say, without a more extensive and systematic study, which path of backscatter evolution is more typical. It is dependent on local meteorological conditions; however, the measurements for supporting such investigations are usually not available. The high backscatter from thin young ice have been attributed to surface roughness and volume scattering associated with the formation of frost flowers [*Hallikainen and Winebrenner, 1992; Onstott*, 1992]. The decrease in backscatter is due to snow collection on the ice surface. A brief description of the physical characteristics of the frost flowers can be found in Martin [1979] and more recently in Richter- Menge and Perovitch [1992]. Martin et al. [1993] have successfully grown salt flowers under laboratory conditions and is currently planning to measure its backscatter characteristics with a scatterometer.

The next question is whether we can make optimal use of the geometric and radiometric information derived from time series SAR data. Kwok et al. [1992] proposed a scheme to measure ice age using area changes but have not used the temporal radiometric information available from recently formed leads. If we can resolve the location and age of lead openings to within the time interval between SAR observation.s, then it seems that the only use of backscatter information would be to improve the estimation of ice thickness and to determine whether frost flowers are present on the ice surface. To date, we do not have sufficient in-situ or laboratory observations of thin ice backscatter (with or without frost flowers) for supporting the use of time series backscatter data from open leads. It would also seem that the time series backscatter data have to be combined with environmental conditions before we can model backscatter dependence on ice growth and ice thickness, and effectively utilize these datasets. Thus, it remains a topic for further investigation.

5. Summary Remarks

We have described an approach for the location of recently opened leads using time series ERS-1 SAR imagery processed at the Alaska SAR Facility. An example was used to illustrate the procedure. The area changes and radiometric evolution of the ice parcel were interpreted. We have demonstrated a useful procedure to unambiguously identify the population of young ice types using geometric information, however it remains difficult to effectively use radiometric information to further estimate the thickness range of sea ice in these leads because of the variability of their backscatter in this growth stage.

Acknowledgments

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References

Hallikainen, M. and D. P. Winebrenner, The Physical Basis for Sea Ice Remote Sensing, in *Microwave Remote Sensing of Sea Ice* (ed. F. Carsey), Geophysical Monograph 68, AGU, 29-464, 1992.

Kwok, R., J.C. Curlander, R. McConnell and S. Pang, An Ice Motion Tracking System at the Alaska SAR Facility, *IEEE J. of Oceanic Engineering, Vol.* 15, No. 1, 44-54, 1990.

Kwok, R. and G. Cunningham, Backscatter Characteristics of The Sea Ice Cover in the Winter Beaufort Sea, to be published in *JGR-Oceans*.

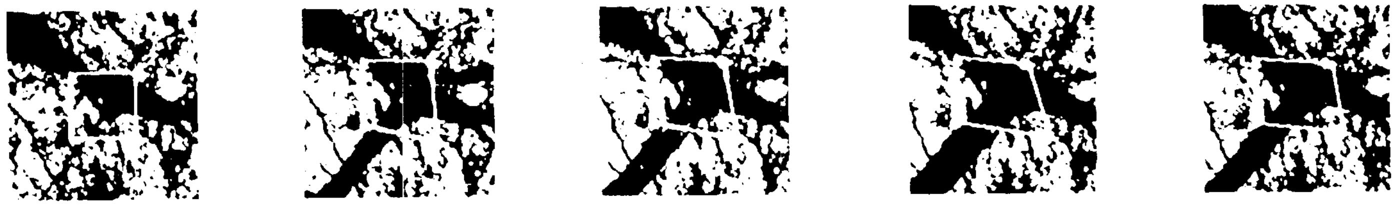
Kwok, R., D. A. Rothrock, H. L. Stern and G.F. Cunningham, Determination of the Age Distribution of Sea Ice using Lagrangian Observations of Ice Motion, Submitted to *IEEE Trans. Geosci. and Remote Sens.*

Martin, S., A Field Study of Brine Drainage and Oil Entrainment in First-year Sea Ice, *J. Glaciol.*, 22(88), 473-502, 1979.

Martin, S., R. Drucker and M. Fort, A Laboratory Study of Salt Flower Growth on the Surface of Young Sea Ice, submitted to *J. Geophy. Res.*

Onstott, R. G., SAR and Scatterometer Signatures of Sea Ice, in *Microwave Remote Sensing of Sea Ice* (ed. F. Carsey), Geophysical Monograph 68, AGU, 73-104, 1992.

Richter-Menge, J. A. and D. K. Perovitch, Surface Characteristics of Lead Ice, presented at the American Geophysical Union Fall Meeting, San Francisco, 1992.



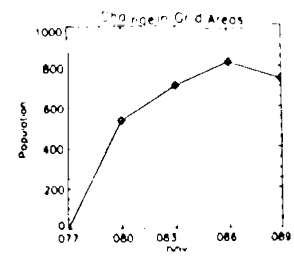


Figure 1. (a) ERS-1 image sequence (Copyright ESA 1994) showing the deformation of an ice parcel. The initial dimension of the ice parcel is 5km x 5km in size. The images are separated by an interval of 3 days. (b) Changes in area of the ice parcel plotted as a function of time. Each area unit is 10000m^2.

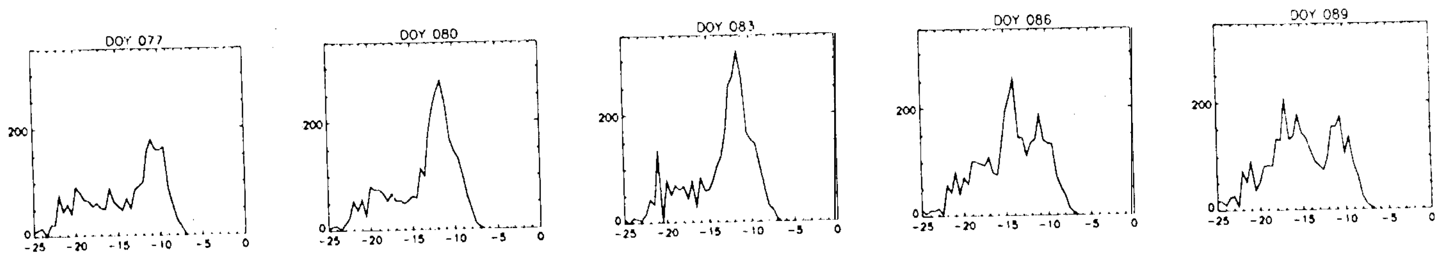


Figure 2. Backscatter histograms of the ice parcel on the different days.

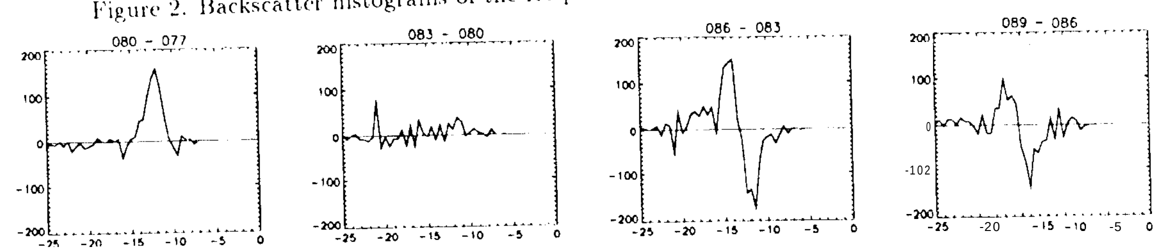


Figure 3. Difference histograms showing changes in the backscatter population between the time intervals.

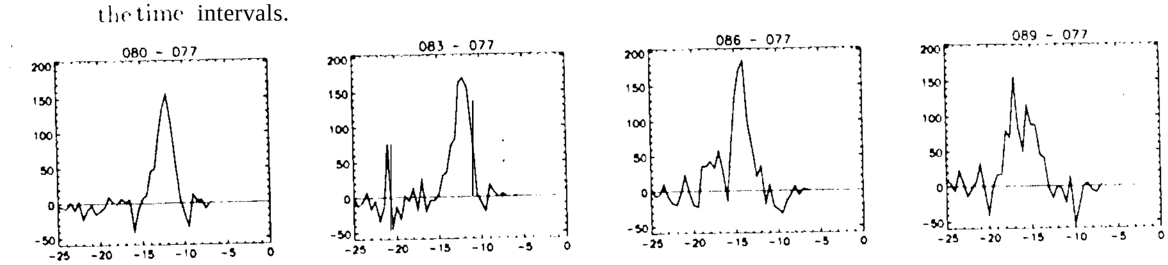


Figure 4. Difference histograms showing changes in the backscatter population relative the first image.

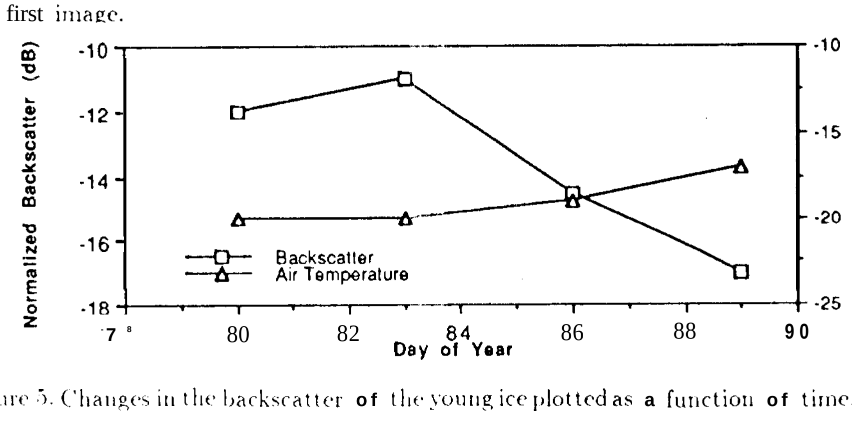


Figure 5. Changes in the backscatter of the young ice plotted as a function of time.